BINDING CONDITION FOR MULTIPLE CUT IN A DRUM MOWER

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Abstract: The present paper describes the kinematics of the mowing mechanism of a conventional drum mower equipped with two blades. It deals with the binding relation between angular velocity of the disc rotation and forward speed, so that the mowed area is cut at least twice while making maximum use of the entirety of the blade length. The article presents a corresponding general mathematical relation fulfilling this condition. If the condition is met, no uncut areas can remain even if one of the blades impacts an obstacle.

Key Words: mower, blade trajectory, cut number, parameters of the mowing mechanism, binding condition

INTRODUCTION

The most commonly used type of mowing machine is the rotary mower. When harvesting fodder crops in agriculture, the most widespread type is the disc mower. They are lightweight, powerful and relatively simple in terms of design. They are produced by all the major manufacturers of agricultural machinery such as Agrostroj, Pöttinger, Krone, Claas, Lely, Deutz-Fahr and many others.

The numerical values of structural dimensions required to draw up graphs correspond to a modern mowing machine Pöttinger Novacat 402 (see Figure 1) – for a detailed description, (Pöttinger 2015). The calculation considers the failure of one of the blades upon impacting an obstacle. It is therefore necessary to establish a ratio between angular velocity and forward speed so that the entirety of the mowed area is cut at least twice.

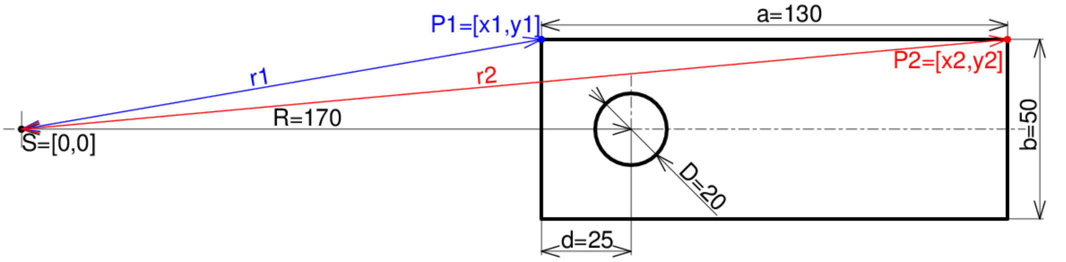
Figure 1 Pöttinger Novacat 402 mower

MATERIAL AND METHODS

Technical parameters of the mowing mechanism

The basic dimensions of the mowing mechanism are shown in the figure (see Figure 2). The blade rotates around the centre of rotation S at an angular velocity of ω. The forward speed V is oriented in the direction of the x axis. The blade edge is delimited by points $P1$ and $P2$. The second blade of the mowing mechanism has the same dimensions and is centrally symmetrical to the first blade. This means that after a half of the work period (i.e. after one half-rotation) the blades switch positions.

Figure 2 Basic diagram of a mowing mechanism of the Pöttinger Novacat 402 mower



Forward movement of one blade length in one half-rotation

It would appear that if the mowing machine travels the maximum of one blade length during one half of a rotation, each point of the mowed area will be cut at least twice. In this, we do not account for the points at the outer edges of the mowed area which will be cut during the next pass, since the strips mowed during each pass overlap. A more detailed inspection shows, however, that this is not the case (see Figure 3), with detail shown in Figure 4.

Figure 3 Areas cut by the individual blades

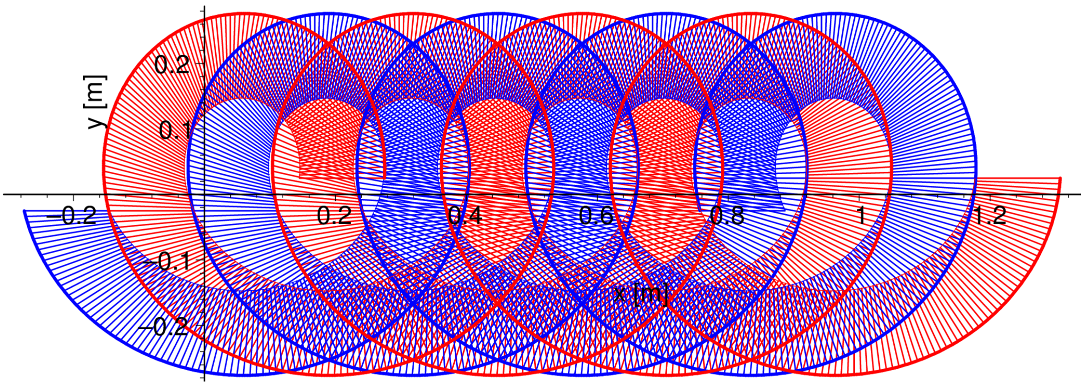
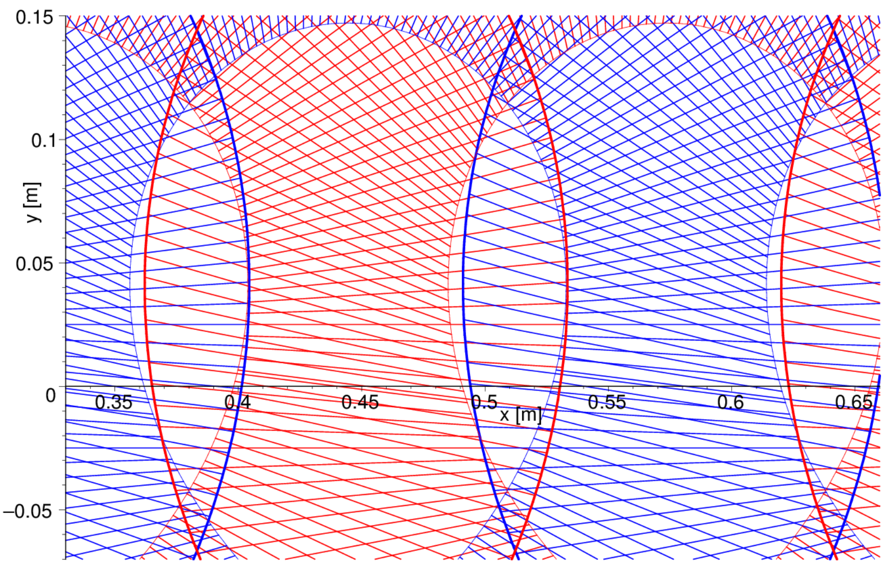


Figure 4 Detail of areas cut only once

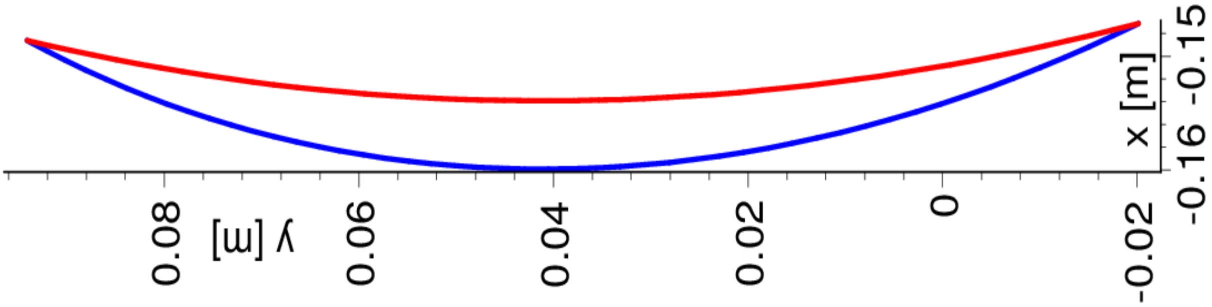


Detailed representation shows that the condition of travelling one blade length during half of the rotation is not sufficient.

Condition for double cut

A detailed analysis of Figure 4 shows that the outlines of the area which was only cut once are delimited by the trajectory of point P2 on the first blade – thick red curve – and the trajectory of point P1 on the second blade – thin blue curve. An accurate representation is shown in Figure 5, which is rotated 90° due to spatial limitations.

Figure 5 Curves delimiting the area cut only once



This area shall be eliminated if both curves come into contact. The condition for the two curves to come into contact can be defined via mathematical relations. Suppose that the point of contact of both curves is located in coordinates *[ξ, η]*. Point *P1* will cross the point of contact in point in time *t1* while point *P2* will cross in *t2*. The following must then be true:

$$[P1(\xi,\eta)] = [P2(\xi,\eta)] \quad \equiv \quad [P1(t1)] = [P2(t2)] \quad \equiv \quad \begin{array}{l} P1_x(t1) = P2_x(t2) \\ P1_y(t1) = P2_y(t2) \end{array}, \tag{1}$$

$$\left.\frac{\dfrac{d\,P1_y(t)}{d\,t}}{\dfrac{d\,P1_x(t)}{d\,t}}\right|_{t=t1} = \left.\frac{\dfrac{d\,P2_y(t)}{d\,t}}{\dfrac{d\,P2_x(t)}{d\,t}}\right|_{t=t2} . \tag{2}$$

Equation (1) means that at times *t1* and *t2*, the points *P1*and *P2* have the same coordinates. Equation (2) shows that at times *t1* and *t2*, they have the same tangent directions and thus can only share a single point of contact. Because the two curves are extended cycloids, they cannot have inflection points. Therefore the system of equations (1) and (2) constitutes a sufficient condition for the derivation of the relation between the angular velocity of blade rotation ω and the forward speed of the mowing machine *V*.

RESULTS AND DISCUSSION

Derivation of the binding condition

The system of equations (1) and (2) can be solved analytically. Given the scope and complexity of the calculation, a computer algebra system Maple 13 was used, (Gander 2014). The program was also used for the creation of all the graphs documenting the process and the results of the calculation.

The solution to the system of equations (1) and (2) are values of *t1*, *t2* and ω which comply with the above system. In the course of the solution, it will quickly be shown that the common tangent must be parallel to the *y* axis, which leads to the following values:

$$t1 = \frac{\alpha 1 + \arcsin\left(\dfrac{V}{R1\,\omega}\right)}{\omega}, \quad t2 = \pi + \frac{\alpha 2 + \arcsin\left(\dfrac{V}{R2\,\omega}\right)}{\omega}, \text{ where } \begin{array}{l} \alpha 1 = \arcsin\left(\dfrac{b}{2R1}\right) \\ \alpha 2 = \arcsin\left(\dfrac{b}{2R2}\right) \end{array} \tag{3}$$

Thus, the corresponding coordinates of the point of contact are:

$$P1 = \frac{1}{\omega}\left[-\left(\sqrt{R1^2\omega^2 - V^2} + V\alpha 1 + V \arcsin\left(\frac{V}{R1\,\omega}\right)\right), V\right],$$
$$P2 = \frac{1}{\omega}\left[-\left(\sqrt{R2^2\omega^2 - V^2} + V\alpha 2 - V\pi + V \arcsin\left(\frac{V}{R2\,\omega}\right)\right), V\right], \tag{4}$$

which leads to the equation:

$$\sqrt{R1^2\omega^2 - V^2} + V\alpha 1 + V \arcsin\left(\frac{V}{R1\,\omega}\right) = \sqrt{R2^2\omega^2 - V^2} + V\alpha 2 - V\pi + V \arcsin\left(\frac{V}{R2\,\omega}\right). \tag{5}$$

If we introduce the binding parameter $K = V/\omega$, we substitute for $\alpha 1$ and $\alpha 2$ from equation (3) and express the rotation radii $R1$ and $R2$ of points $P1$ and $P2$ from Figure 1, we arrive at the final shape of the binding condition:

$$\sqrt{\frac{C2\,K^2 - 1}{4}} - \arcsin\left(\frac{b}{C2}\right) + \pi - \arcsin\left(\frac{2}{\sqrt{C2\,K}}\right) + \sqrt{\frac{C1\,K^2 - 1}{4}} + + \arcsin\left(\frac{b}{C1}\right) + \arcsin\left(\frac{2}{\sqrt{C1\,K}}\right) = 0, \quad \text{where} \quad \begin{aligned} C1 &= 4\,R^2 - 8\,R\,d + 4\,d^2 + b^2 \\ C2 &= C1 + 8\,R\,a - 8\,d\,a + 4\,a^2 \end{aligned}. \tag{6}$$

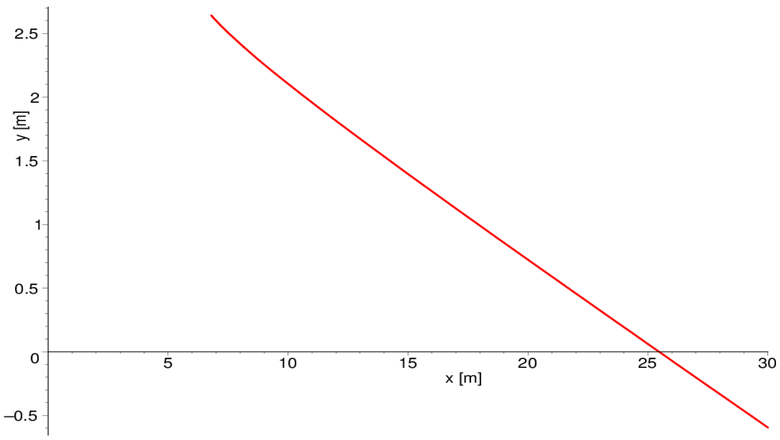
Binding condition for Pöttinger Novacat 402

Equation (6) is used for the calculation of coefficient K. The calculation must be performed numerically, since equation (6) for K is transcendental. The resulting value of coefficient K is dependent only on the basic dimensions of the cutting disc with blades, i.e. on the length of the active edge of the blade a, the width of the blade b, the distance of the mounting hole of the blade from its inner edge d and the rotation radius R, see Figure 2. If we substitute the specific dimensions of the Pöttinger Novacat 402 reaping machine, see Figure 2, equation (6) will look as follows:

$$\sqrt{0.07625\,K^2 - 1} - 3.22167 + \arcsin\left(\frac{3.62143}{K}\right) - \sqrt{0.02165\,K^2 - 1} - \arcsin\left(\frac{6.79628}{K}\right) = 0 \tag{7}$$

The left side of equation (7) can be drawn in a graph as a function of variable K, see the graph in Figure 6. From this graph, we can determine the approximate value of K, where equation (7) is met and the exact value of K can be computed numerically via iterative methods (Maurer 2005)

Figure 4 Graph of the functional values of the left side of equation (7)



$$K \equiv \frac{V}{\omega} \leq 25.46382939\ [\mathbf{m}]. \tag{8}$$

CONCLUSION

The use of the resulting equation is absolutely universal, meaning that it can be used for any drum mower which is equipped with two blades per drum. All that is required are the basic parameters of the disc mowing unit, which can then easily be used to calculate parameter *K*. The value of parameter *K* then allows for a simple determination of the maximum working speed at given disc revolutions or the minimum disc revolutions at the selected working speed. The edge of the mowing blade will be utilized in its entire active length with the condition that the entire mowed area will be cut at least twice. Even if one of the blades fails, as can occur when one of the blades encounters an obstacle, the area will still be harvested in full.

The generalization of the binding equation for multiple blades on a single drum or potentially for a different blade shape (trapezoidal) is very simple.

As can be found in the technical documentation the binding condition (6–8) between forward speed and angular velocity is fully satisfied, see (Pöttinger. 2015A) for an example.

ACKNOWLEDGEMENT

The research has been supported by the project TP 4/2014 "Analysis of degradation processes of modern materials used in agricultural technology" financed by IGA AF MENDELU.

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